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Yuan, Sen; Fioranelli, Francesco; Yarovoy, Alexander

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Robust High-resolution Imaging with Unambiguous Doppler Beam Sharpening for Forward-looking Automotive Radar

Sen Yuan, Francesco Fioranelli, and Alexander Yarovoy
MS3 Group, Department of Microelectronics, Delft University of Technology,
{S.Yuan-3, F.Fioranelli, A.Yarovoy}@tudelft.nl

***Abstract*—This paper presents an approach based on Doppler beam sharpening (DBS) to enhance the resolution of multiple 'dynamic' targets in automotive driving scenarios. The ambiguity inherent to the forward-looking DBS and the coupling between azimuth and elevation angles are jointly addressed with the proposed method. Demonstrated experimental results show the feasibility of the proposed technique in automotive radar sensing.**

I. Introduction

Radar is a key sensor in automotive for its sensing ability in adverse weather conditions [1]. Currently, 3+1D radars with range, azimuth, and elevation plus Doppler information have attracted significant interest for perception tasks such as scene segmentation and imaging. The quality of 3D imaging will highly rely on the radar spatial resolution in terms of azimuth and elevation. These angular resolutions are contingent upon the antenna aperture and thus are determined by the number and placement of the transmitting and receiving antenna elements, which are in turn limited by the radar cost and packaging size. Even with Multiple Input Multiple Output (MIMO) technology, the resolution is still insufficient for the imaging requirements. Using motion information for resolution enhancement is a major trend in automotive radar, and a good deal of research has been conducted in this field [2]–[5].

In this paper, a novel robust 3D high-resolution imaging algorithm using Doppler beam sharpening (*3DRUDAT*) is proposed and implemented in the forward-looking region, which is particularly relevant for autonomous vehicles. The performance of the proposed algorithm is experimentally evaluated to enhance the imaging resolution in a realistic automotive driving scenario.

II. Proposed robust DBS algorithm

A. The algorithm

After implementing de-chirping on the received RF signal, this is converted into a baseband signal for later processing. The range Fast Fourier Transform (FFT) will be performed on fast time domain to obtain the range of targets. For a certain range bin, its corresponding antenna signal and Doppler signal will be derived for subsequent processing. The Doppler beam sharpening will be implemented on the Doppler signal by joint elevation and azimuth steering vector, providing an ambiguous and coupled profile. The antenna signal will be used to implement both elevation and azimuth beam forming separately. Then, an extra frequency shift, auto-convolution, and adaptive threshold are introduced to solve the ambiguity and coupling from DBS in each pixel. The 3DRUDAT algorithm is presented in more detail in [6].

B. Experimental results

The proposed approach is verified by experimental data. The radar used is the TI AWRx cascade radar, mounted on top of the vehicle shown in Fig. 1. The radar is installed next to a GoPro camera, while a Lidar is on the top-middle of the car. The radar operates at 77GHz. The radar parameters are specified as follows: the starting frequency of the chirp f_0 is 77 GHz, the chirp bandwidth B is 2 GHz, the chirp duration T_c is 25 μs, the sampling rate f_s is 64 Msps, and L = 512 chirps are processed in each frame. The MIMO antenna on the forward-looking radar is located at the coordinate centre.

Fig. 1: Car with multiple sensors used for the data collection

The following figures present images captured by different sensors for the same scenarios for comparison. In Fig. 2, imagery from a GO-pro camera offers an empirical interpretation of the scenario, with key targets such as a bus stop, rubbish bin, and display marked.

Fig. 3 and 4 show radar images using different configurations. Fig. 3 uses all 86 antenna elements in the cascade radar, offering enhanced spatial resolution. In contrast, Fig. 4 uses only 8 antenna elements from the radar, similar to commercial simpler radar with 2x4 MIMO configuration.

Fig. 5 demonstrates the results obtained using our proposed 3DRUDAT algorithm with the same 8 antenna elements. Remarkably, our proposed method appears to outperform

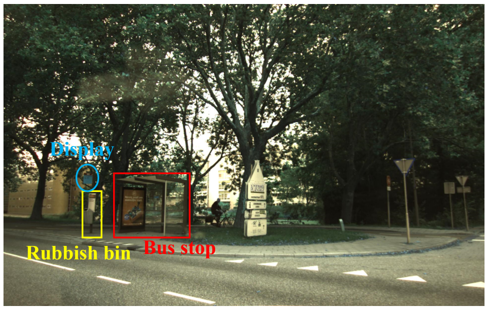

Fig. 2: The optical image from the camera.

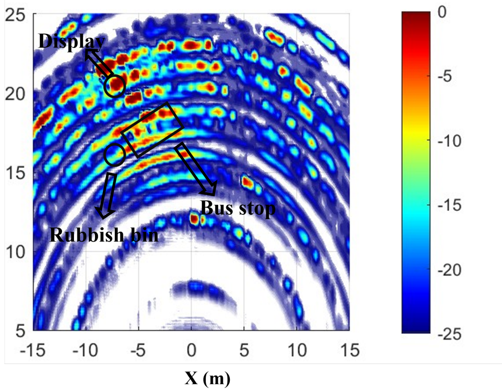

Fig. 3: The radar imaging results using all 86 elements.

the larger array (Fig.3), highlighting the effectiveness and advantage of our approach in achieving improved resolution.

These visual comparisons show the distinct strengths and capabilities of each sensing modality, with our proposed 3DRUDAT method exhibiting particular promise in achieving high resolution even with a limited number of antenna elements. Notably, when using a small number of antenna elements, some targets begin to emerge on the right side of the figure. However, due to the limited resolution, these targets tend to merge together, forming a high-energy block. In the proposed method, the image from the small array serves as one of the inputs, thus introducing the targets in the same positions.

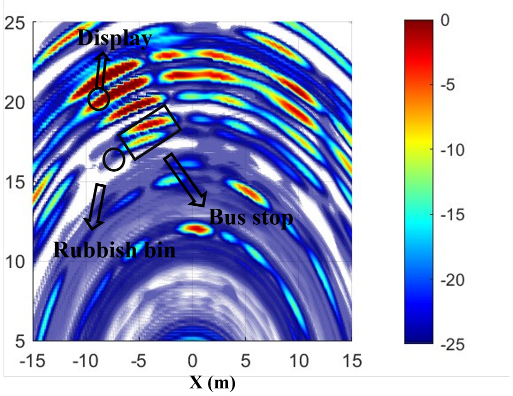

Fig. 4: The radar imaging results using only 8 elements.

Furthermore, the side lobe level for the bus stop in Fig. 3 is measured at -20 dB, while in Fig. 4, the side lobe level increases to -2.3 dB. This increase in side lobe level is attributed to the accumulated energy from the targets themselves when using more antenna elements, resulting in an improved Signal-to-Noise Ratio (SNR). In the case of the proposed method, which enhances SNR through the multiplication of results from Doppler beam sharpening (DBS) and Beamforming, the side lobe level in Fig. 5 is notably low at -30 dB.

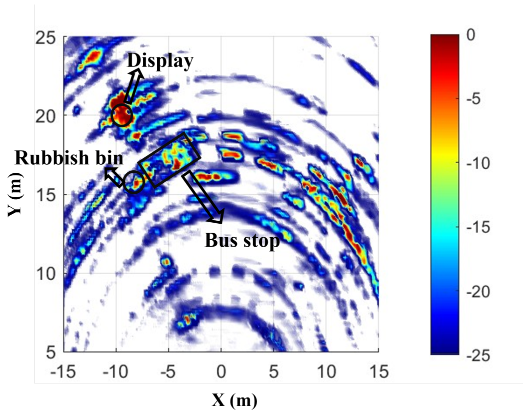

Fig. 5: The imaging results using 8 elements with the proposed *3DRUDAT* algorithm.

III. Conclusions

A novel algorithm (*3DRUDAT*) to focus and enhance the resolution of multiple dynamic targets in an automotive scenario has been presented. By combining the traditional DBS with MIMO processing, the developed technique overcomes current limitations in radar-based autonomous sensing and efficiently focuses on dynamic targets. Future work will address adaptive focusing on the moving targets for the autonomous platforms.

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